CLAIMS

1. A magnetic recording medium comprising:

a substrate;

an underlying layer which is formed on the substrate, the underlying layer being composed of crystal grains substantially formed of magnesium oxide, and a crystal grain boundary containing at least one oxide selected from the group consisting of silicon oxide, aluminum oxide, titanium oxide, tantalum oxide, and zinc oxide; and

a magnetic layer which is formed on the underlying layer and on which information is recorded.

2. The magnetic recording medium according to claim 1, wherein the crystal grains are arranged in a honeycomb configuration.

3. The magnetic recording medium according to claim 2, wherein an average number of the crystal grains deposited around each of the crystal grains is 5.9 to 6.1.

4. The magnetic recording medium according to claim 1, wherein the crystal grains are subjected to crystal orientation in a certain direction.

5. The magnetic recording medium according to claim 1,

wherein the magnetic layer is epitaxially grown on the underlying layer.

6. The magnetic recording medium according to claim 1, wherein a standard deviation of a grain diameter distribution of the crystal grains is not more than 8 % of an average grain diameter.

7. The magnetic recording medium according to claim 1, wherein the magnetic layer includes magnetic grains grown corresponding to the respective crystal grains of the underlying layer, and a boundary between the magnetic grains.

8. The magnetic recording medium according to claim 7, wherein the boundary has a width of 0.5 to 2 nm.

9. The magnetic recording medium according to claim 1, wherein a difference between a lattice constant of the crystal grains of the underlying layer and a lattice constant of magnetic grains of the magnetic layer is within ±10 %.

10. The magnetic recording medium according to claim 1, wherein the underlying layer is formed by means of an ECR sputtering method.

11. A magnetic recording medium comprising:

a substrate;

a first underlying layer which is formed on the substrate;

a second underlying layer which is formed on the first underlying layer; and

a magnetic layer which is formed on the second underlying layer and on which information is recorded, wherein:

the second underlying layer is composed of crystal grains substantially formed of at least one oxide selected from the group consisting of cobalt oxide, chromium oxide, iron oxide, nickel oxide, and magnesium oxide, and a crystal grain boundary containing at least one oxide selected from the group consisting of silicon oxide, aluminum oxide, titanium oxide, tantalum oxide, and zinc oxide; and

the first underlying layer serves as a layer to prevent the second underlying layer from initial growth.

12. The magnetic recording medium according to claim 11, wherein the first underlying layer is an amorphous film, and the amorphous film includes a metal selected from the group consisting of hafnium, titanium, tantalum, niobium, zirconium, tungsten, molybdenum, and an alloy containing at least one element thereof; a cobalt alloy principally composed of cobalt and containing at least one element selected from the group consisting of titanium, tantalum,

niobium, zirconium, and chromium; or at least one inorganic compound selected from the group consisting of silicon nitride, silicon oxide, and aluminum oxide.

13. The magnetic recording medium according to claim 11, wherein the crystal grains are arranged in a honeycomb form.

14. The magnetic recording medium according to claim 11, wherein the first underlying layer is a crystalline film, and the crystalline film includes at least one selected from the group consisting of chromium, chromium alloy, vanadium, and vanadium alloy.

15. The magnetic recording medium according to claim 14, wherein the alloy is an alloy containing at least one element selected from the group consisting of titanium, tantalum, aluminum, nickel, vanadium, and zirconium.

16. The magnetic recording medium according to claim 11, wherein the first underlying layer has a film thickness of 2 nm to 50 nm.

17. The magnetic recording medium according to claim 11, wherein the first underlying layer and the second underlying layer are formed by using an ECR sputtering

method.

18. The magnetic recording medium according to claim 11, wherein the magnetic layer is a granular type magnetic layer.

19. The magnetic recording medium according to claim 18, wherein the first underlying layer is formed of hafnium, and the second underlying layer is formed of $CoO-SiO_2$.

20. The magnetic recording medium according to claim 11, wherein a difference between a lattice constant of the crystal grains of the second underlying layer and a lattice constant of magnetic grains of the magnetic layer is within ±10 %.

21. A magnetic recording medium comprising:

a substrate;

an underlying layer which is formed on the substrate;

a control layer which is formed on the underlying layer and which is formed of at least one selected from the group consisting of magnesium oxide, chromium alloy, and nickel alloy; and

a magnetic layer which is formed on the control layer and on which information is recorded, wherein:

the underlying layer is composed of crystal grains

substantially formed of at least one oxide selected from the group consisting of cobalt oxide, chromium oxide, iron oxide, nickel oxide, and magnesium oxide, and a crystal grain boundary containing at least one oxide selected from the group consisting of silicon oxide, aluminum oxide, titanium oxide, tantalum oxide, and zinc oxide.

22. The magnetic recording medium according to claim 21, wherein the control layer is an alloy containing chromium or nickel as a major component, and at least one element selected from the group consisting of chromium, titanium, tantalum, vanadium, ruthenium, tungsten, molybdenum, niobium, nickel, zirconium, and aluminum.

23. The magnetic recording medium according to claim 21, wherein the control layer is formed of one selected from the group consisting of chromium-titanium, chromium-tungsten, magnesium oxide, chromium-ruthenium.

24. The magnetic recording medium according to claim 21, wherein the control layer has a bcc or B2 structure.

25. The magnetic recording medium according to claim 21, wherein the control layer is epitaxially grown from the underlying layer, the control layer has a structure which reflects a crystal structure of the underlying layer, and the

control layer has a crystalline portion which is constructed by crystal grains corresponding to the crystal grains of the underlying layer, and a grain boundary which corresponds to the crystal grain boundary of the underlying layer.

26. The magnetic recording medium according to claim 21, wherein the control layer has a film thickness of 2 nm to 10 nm.

27. The magnetic recording medium according to claim 21, wherein a combination of the underlying layer, the control layer, and the magnetic layer is at least one combination selected from the group consisting of CoO-ZnO/Cr-Ti alloy/Co-Cr-Pt alloy, CoO-SiO_2/MgO/Co-Cr-Pt-Ta alloy, CoO-SiO_2/Cr-W alloy/Co-Cr-Pt-Ta alloy, CoO-SiO_2/MgO/CoO-SiO_2 granular type magnetic film, CoO-SiO_2/Ni-Al alloy/Co-Cr-Pt-Ta alloy, CoO-SiO_2/Cr-Ti alloy/Co-Cr-Pt-Ta alloy, CoO-SiO_2/Ni-Ta alloy/Co-Pt-SiO_2 granular type magnetic film, CoO-SiO_2/Ni-Ta alloy/Co-Cr-Pt-Ta alloy, CoO-SiO_2/Cr-Ru alloy/Co-Cr-Pt-Ta alloy, CoO-SiO_2/Cr-Ru alloy/Co-Pt-SiO_2 granular type magnetic film, CoO-SiO_2/Co-Cr-Zr alloy/Co-Pt-SiO_2 granular type magnetic film, CoO-SiO_2/Co-Cr-Zr alloy/Co-Cr-Pt-Ta alloy, CoO-SiO_2/Cr-Mo alloy/Co-Cr-Pt-Ta alloy, and CoO-SiO_2/Cr-Mo alloy/Co-Pt-SiO_2 granular type magnetic film.

28. The magnetic recording medium according to claim

21, wherein differences between a lattice constant of the crystal grains of the underlying layer and a lattice constant of crystal grains of the control layer and between the lattice constant of the crystal grains of the control layer and a lattice constant of magnetic grains of the magnetic layer are within ±5 % respectively.

29. The magnetic recording medium according to claim 21, wherein the crystal grains of the underlying layer are arranged in a honeycomb configuration.

30. The magnetic recording medium according to claim 21, wherein the underlying layer and the control layer are formed by means of an ECR sputtering method.

31. A magnetic recording medium comprising:

a substrate;

an underlying layer which is formed on the substrate; and

a magnetic layer which is formed on the underlying layer and on which information is recorded, wherein:

the underlying layer is composed of crystal grains and a crystal grain boundary which surrounds the respective crystal grains, the crystal grains being arranged in a honeycomb configuration; and

the crystal grains protrude at a height of 3 to 20 nm

from a surface of the underlying layer.

32. The magnetic recording medium according to claim 31, wherein the underlying layer is formed by means of an ECR sputtering method, the crystal grain is substantially formed of at least one oxide selected from the group consisting of cobalt oxide, chromium oxide, iron oxide, nickel oxide, and magnesium oxide, and the crystal grain boundary is substantially composed of at least one oxide selected from the group consisting of silicon oxide, aluminum oxide, titanium oxide, tantalum oxide, and zinc oxide.

33. The magnetic recording medium according to claim 31, wherein the underlying layer has a film thickness of 10 nm to 100 nm.

34. The magnetic recording medium according to claim 31, further comprising a protective layer on the magnetic layer, wherein each of the magnetic layer and the protective layer has projections which protrude at a height of 3 to 20 nm from a surface of each of the magnetic layer and the protective layer while reflecting a surface structure of the underlying layer.

35. The magnetic recording medium according to claim 34, wherein the projections are used as a texture.

36. The magnetic recording medium according to claim 35, wherein a distance between the adjoining projections is 10 to 30 nm.

37. The magnetic recording medium according to claim 31, wherein the crystal grain boundary has a width of 0.5 to 2 nm.

38. A magnetic recording medium comprising:

a substrate;

an underlying layer which is formed on the substrate; and

a magnetic layer which is formed on the underlying layer, wherein:

the underlying layer exhibits soft magnetization, and the underlying layer is composed of crystal grains substantially formed of at least one oxide selected from the group consisting of cobalt oxide, chromium oxide, iron oxide, nickel oxide, and magnesium oxide, and a crystal grain boundary containing at least one oxide selected from the group consisting of silicon oxide, aluminum oxide, titanium oxide, tantalum oxide, and zinc oxide.

39. The magnetic recording medium according to claim 38, wherein the underlying layer has a coercive force of 0.05

Oe to 10 Oe and a relative permeability of 100 to 10000.

40. The magnetic recording medium according to claim 38, wherein the crystal grains are arranged in a honeycomb configuration.

41. The magnetic recording medium according to claim 38, wherein the magnetic recording medium is irradiated with light when information is recorded or reproduced.

42. The magnetic recording medium according to claim 41, wherein ECR sputtering is carried out in a reducing atmosphere.

43. The magnetic recording medium according to claim 38, wherein the underlying layer has in-plane magnetization.

44. A magnetic recording medium comprising:

a substrate;

an underlying layer which is formed on the substrate; and

a magnetic layer which is formed on the underlying layer and which has an easily magnetized direction in a direction perpendicular to a substrate surface, wherein:

the underlying layer is composed of crystal grains substantially formed of at least one oxide selected from the

group consisting of cobalt oxide, chromium oxide, iron oxide, nickel oxide, and magnesium oxide, and a crystal grain boundary containing at least one oxide selected from the group consisting of silicon oxide, aluminum oxide, titanium oxide, tantalum oxide, and zinc oxide which surrounds the respective crystal grains.

45. The magnetic recording medium according to claim 44, wherein the crystal grains are pillar-shaped in a plane perpendicular to the substrate surface and hexagonal in a plane parallel to the substrate surface, and the crystal grains are arranged in a honeycomb configuration in the plane parallel to the substrate surface.

46. The magnetic recording medium according to claim 45, wherein the crystal grains and the crystal grain boundary are non-magnetic.

47. The magnetic recording medium according to claim 45, wherein the crystal grains of the underlying layer are oriented in (111) orientation.

48. The magnetic recording medium according to claim 47, wherein the magnetic layer is oriented in (00.1) orientation.

49. The magnetic recording medium according to claim 45, further comprising a soft magnetic layer which is provided between the substrate and the underlying layer.

50. The magnetic recording medium according to claim 45, further comprising, on the underlying layer, a control layer which controls crystalline orientation of the magnetic layer.

51. The magnetic recording medium according to claim 45, wherein the magnetic layer is a ferromagnetic layer which is composed of an alloy principally containing Co and containing at least two elements selected from the group consisting of Cr, Pt, Ta, Nb, Ti, and Si.

52. The magnetic recording medium according to any one of claims 1, 11, 21, 31, 38, and 44, further comprising a protective film having a film thickness of 1 to 5 nm.

53. The magnetic recording medium according to claim 52, wherein the protective film is formed by means of an ECR sputtering method.

54. A magnetic recording apparatus comprising the magnetic recording medium as defined in any one of claims 1, 11, 21, 31, 38, and 44.

55. A method for producing a magnetic recording medium comprising, on a substrate, a magnetic layer for recording information thereon and a protective layer, the method comprising:

generating plasma by means of resonance absorption;

allowing the generated plasma to collide with a target so that target particles are sputtered; and

applying a bias voltage between the substrate and the target to introduce and deposit the sputtered target particles on the substrate, whereby forming at least one layer of the magnetic layer and the protective layer.

56. The method for producing the magnetic recording medium according to claim 55, wherein a microwave is used for the resonance absorption.

57. The method for producing the magnetic recording medium according to claim 55, wherein the bias voltage is applied with an alternating current power source having a radio frequency or a direct current power source.

58. The method for producing the magnetic recording medium according to claim 55, wherein the target for the protective layer is carbon.

59. The method for producing the magnetic recording medium according to claim 55, wherein when the protective layer is formed, then the target is carbon, and a mixed gas, which principally contains argon and which contains at least one of nitrogen and hydrogen, is used as a plasma gas.

60. A method for producing a magnetic recording medium comprising, on a substrate, an underlying layer and a magnetic layer for recording information thereon, the method comprising:

generating plasma by means of resonance absorption;

allowing the generated plasma to collide with a target so that target particles are sputtered; and

applying a bias voltage between the substrate and the target to introduce and deposit the sputtered target particles on the substrate, whereby forming the underlying layer.

61. The method for producing the magnetic recording medium according to claim 60, wherein at least one selected from the group consisting of cobalt oxide, chromium oxide, iron oxide, nickel oxide, and magnesium oxide, and at least one selected from the group consisting of silicon oxide, aluminum oxide, titanium oxide, tantalum oxide, and zinc oxide are used as the target.

62. The method for producing the magnetic recording medium according to claim 60, wherein the target particles are sputtered in a reactive atmosphere containing oxygen.

63. The method for producing the magnetic recording medium according to claim 60, wherein:

the magnetic recording medium further comprises a protective layer on the magnetic layer; and

the protective layer and the magnetic layer are formed respectively by generating the plasma by means of the resonance absorption, allowing the generated plasma to collide with the target so that the target particles are sputtered, and applying the bias voltage between the substrate and the target to introduce and deposit the sputtered target particles on the substrate.

64. The method for producing the magnetic recording medium according to claim 63, wherein when the protective layer is formed, then the target is carbon, and a mixed gas, which principally contains argon and which contains at least one of nitrogen and hydrogen, is used as a plasma gas.

65. The method for producing the magnetic recording medium according to claim 60, wherein a microwave is used for the resonance absorption.

66. The method for producing the magnetic recording medium according to claim 60, wherein the bias voltage is applied with an alternating current power source having a radio frequency or a direct current power source.